NASA TT F-10,062

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INTENSITY OF METHANE ABSORPTION IN 6190 Å BAND ON JUPITER'S DISK

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Translation of "Ob intensivnosti metanovogo pogloshcheniya v polose CH_4 6190 Å na diske Yupitera" Izvestiya Akademii Nauk Kazakhskoy SSR, Seriya Fiziko-Matematicheskikh Nauk, (Astrofizika), Vol. 16, No. 1, 61-73, 1963

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON APRIL 1966

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ABSTRACT /161*

Measurements were made of the 6190 Å absorption band intensity in the spectra of the equatorial zone and two temperate zones of Jupiter in 1959-61. The observations were made in order to detect the possible variations in the intensity of the band as a function of time and the position of the investigated zone on Jupiter's disk.

It was established that the width of the 6190 Å band was the same for all of the investigated zones of Jupiter. There is an indication of small variations in the band intensity from one night to another. These variations are not associated with solar activity or with the longitude of the central meridian of the planet.

The possible reasons for these variations are as follows: the change in the thickness of the pure gas layer which is over the cloud layer and photochemical processes in the atmosphere of Jupiter. The first reason seemed more likely. The change in the altitude of the upper boundary of the cloud layer determined from the observed variations in the methane band intensity is approximately 4 kilometers. The extent of the pure gas layer in Jupiter's atmosphere coincides with that for the earth's atmosphere if we take into account Kuiper's model "b" and the

* Numbers in margin indicate pagination in original foreign text.

results published in Reference 4. The optical thickness of the pure gas layer in the continuous spectrum is very small — from 0.0059 at a wavelength of 4000 Å to 0.0009 at a wavelength of 6500 Å.

The 6190 Å band is the most intense absorption band of methane in the visible region of Jupiter's spectrum which can be photographed using isopanchromatic materials. Its observation is not particularly difficult due to the utilization of high sensitivity plates with a small dispersion of the spectograph. At the same time data on the variations in the intensity of this band can be related to other methane bands because when such measurements are practical, their cause must lie, first of all, in the variations of the optical thickness of the methane layer which are the same for all bands. The possible differences in the variation of band intensity corresponding to different vibration levels could hardly be detected by means of a spectograph with small dispersion.

Measurements of the 6190 Å band intensity have been carried out frequently for the purpose of determining its variation as a function of the position of the investigated region on Jupiter's disk. The first observations at the end of the 19th century and at the beginning of the 20th century produced rather inconsistent results in this respect which can be explained by the low accuracy of evaluating intensities which were carried out primarily by means of the naked eye rather than by using the photometry of the absorption band profile. From the standpoint of photometry, the observations of Hess (Reference 1) are most strict but are based on only several spectrograms of Jupiter. The structure of the methane bands and of the ammonia bands in the spectrum of Jupiter has been investigated recently by Kiess and Corliss (Reference 2) who used a diffraction spectrograph of high dispersion at the Mauna Loa Observatory in Hawaii. However, in this work too, the intensity of lines in the absorption bands was evaluated only by means of an arbitrary visual scale without photometry.

During his spectrophotometric observations of Jupiter in 1949, Hess used a spectrograph with a dispersion of 43 Å mm between the C and D lines and obtained an equivalent 6190 Å band width of 16.2 ± 1.9 Å at the Equator (the total number of spectrograms was n = 5). The maximum deviation of the equivalent width from the equitorial width is observed at the jovicentric latitude of 30° and constitutes −4.0 ± 1.0 Å (n = 4), while at the latitudes of 162 10° and 60° the deviations are almost the same and are equal to − 2.5 and − 2.3 Å respectively.

In a preceding work (References 3, 4) V. G. Teyfel', who made observations in 1958, established that the intensity distribution over Jupiter's disk along the Equator and the meridian in the methane absorption band 6190 Å and 5430 Å is identical to the intensity distribution in adjoining regions of the continuous spectrum and shows no anomalies in latitude zones near 30°. The purpose of future observations is to verify these results by determining the intensity of absorption bands in three zones of Jupiter's disk and establishing the limits of possible variations in the intensity of methane bands as a function of time.

RESULTS OF THE OBSERVATIONS

In 1959 spectral observations of Jupiter were carried out which were analogous to the observations made by Hess. Since the low position of Jupiter did not make it possible to investigate sufficiently narrow zones of the planet due to the vibration of the image, readings were made of the spectra of equatorial (E) and of temperate zones — the north (N) and the south (S) — of focal image of Jupiter on the AZT-7 200 mm telescope with an AST-9 spectrograph (the dispersion was 143 Å/mm for H_γ). The image of Jupiter was displaced along the slit of the spectrograph due to its diurnal motion. The slit was placed parallel to Jupiter's equator and its position over a definite zone of the planet was maintained by rotating the inclination key.

The exposure time was determined by the number of the planet's image passages along the slit of the spectrograph. The same number of passages was observed for all of the zones and usually these were equal to two. The high brightness and extent of the equatorial zone was compensated by stopping down the input pupil of the instrument. The spectra were photographed by using the Kodak OaE plates. These plates turned out to be more suitable for constructing the contours of the 6190 Å absorption band than the Agfa Spektral Rot Rapid plates used earlier since the latter have a small drop in sensitivity near the long wave wing of the band. In the case of the Kodak OaE plates the variation in the spectral sensitivity in this region takes place along a straight line (Figure 1).

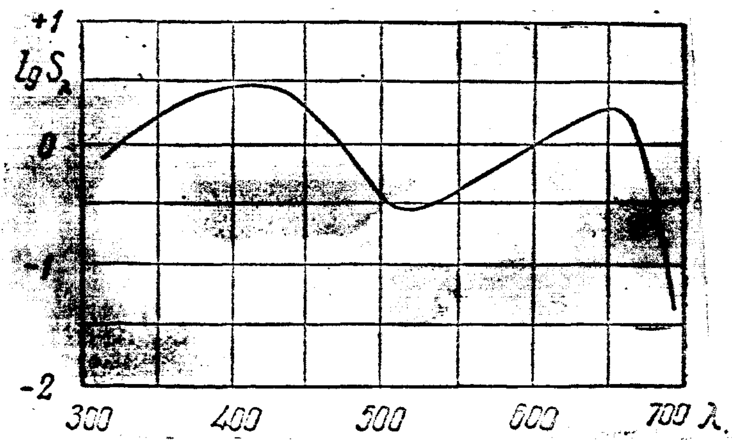

Figure 1. The spectral sensitivity of the Kodak OaE plates (according to Breydo and Markelova).

Since the investigated region of the spectrum had negative densities corresponding to the linear regions of the characteristic curve, the processing of the spectrograms was somewhat simplified because it was possible to draw the lines of the continuous spectrum in a region of absorption bands by the direct use of contours constructed on the basis of the densities. Since the variation in the sensitivity of the plates in this region takes place along a straight line and since we can neglect the variation in the dispersion in the red part of the spectrum within the limits 100 – 200 Å, the interpolated continuous spectrum in the absorption band is represented by a straight line. The total 6190 Å band width on the spectrogram is approximately 0.35 mm (approximately 160 Å). The density measurements during the construction of the contours were made every 0.02 mm. The width of the spectrograph was sufficiently large so that it was possible to use the maximum height of the microphotometer slit and to reduce to a minimum the effect of the negative grain on the contour of the absorption band.

During the period May – June 1959, 220 spectograms of Jupiter were obtained and of these, 201 were processed. Their number has the following distribution according to zones: E — 66, N — 65, S — 70. The equivalent width W_{band} and the depth at the center of the band R_{band} were determined from the constructed contours of the band.

The results of the measurements are presented in Tables 1 and 2. Table 1 contains the following: the average values of W_{band} in Å for each of the investigated zones of Jupiter, σ the root – mean – square error of one measurement of W_{band}, n — the number of measured spectograms, $\overline{W}'_{band}$ the average value of the equivalent band width for the entire disk, σ' the root – mean – square error for $\overline{W}'_{band}$.

Table 1

1959	E			N			S			All zones	
	W_{band}	σ	n	W_{band}	σ	n	W_{band}	σ	n	$\overline{W}_{band}$	σ
		±			±			±			±
8—9 May	16.8	1.2	2	18.3	0.3	2	18.1		1	17.6	1.2
12—13 "	17.8	—	1	16.8	0.1	2	15.8	1.0	3	16.4	1.0
19—20 "	16.0	1.9	4	16.2	0.4	2	16.4	0.3	3	16.1	1.2
25—26 "	18.9	0.4	3	15.2	1.8	4	15.6	0.9	3	16.4	2.1
26—27 "	18.2	1.0	3	16.6	1.4	3	16.8	0.8	4	17.1	1.2
24—25 June	18.1	2.0	9	17.8	2.0	9	18.3	1.5	9	18.1	1.3
26—27 "	17.9	1.6	3	17.1	0.2	3	17.0	1.5	3	17.3	1.2
27—28 "	19.2	1.1	8	18.2	2.0	9	18.4	1.8	9	18.6	1.7
28—29 "	18.6	1.3	9	19.2	1.8	7	18.8	0.9	10	18.8	1.1
9—10 July	18.4	1.3	8	18.4	1.1	9	17.7	1.4	8	18.2	1.3
13—14 "	21.1	1.3	4	19.1	0.8	3	21.2	2.1	4	20.6	1.7
16—17 "	19.9	1.3	3	20.0	1.2	4	20.0	1.1	4	20.0	1.1
17—18 "	18.0	1.4	5	18.1	1.4	5	18.1	1.1	5	18.1	1.2
20—21 "	17.9	1.4	4	18.3	1.9	3	18.8	0.8	4	18.3	1.3

Table 2 shows the values R_{band} and the root - mean - square errors of one measurement σ from data for each of the zones. The average values of W_{band} and R_{band} for the entire period are contained in Table 3 where σ_W and σ_R are the root - mean - square deviations of W_{band} and R_{band} respectively.

Let us consider first the data in Table 3. As we can see from the table the average equivalent width and depth of the 6190 Å band is practically the same for all three zones of Jupiter and there is no sharp deviation in the temperate zones as noted by Hess. The data of Table 1 also show that there is no systematic variation between the zones in the direction of smaller values of W_{band} for N and S. Thus the absence of absorption band intensity variation as a function of position on Jupiter's disk as observed in 1958 is confirmed. 164

Table 2

1959	E		N		S	
	R_{band}	σ	R_{band}	σ	R_{band}	σ
8–9 MAY	0.202	± 0.020	0.210	± –	0.200	± –
12–13 "	0.200	–	0.185	0.005	0.179	0.013
19–20 "	0.199	0.022	0.202	0.002	0.187	0.014
25–26 "	0.215	0.005	0.171	0.017	0.187	0.013
26–27 "	0.218	0.008	0.178	0.003	0.186	0.018
24–25 JUNE	0.212	0.017	0.210	0.019	0.208	0.015
26–27 "	0.202	0.016	0.196	0.004	0.200	0.007
27–28 "	0.212	0.013	0.206	0.012	0.210	0.010
28–29 "	0.216	0.014	0.206	0.011	0.214	0.009
9–10 JULY	0.196	0.012	0.198	0.006	0.193	0.012
13–14 "	0.230	0.012	0.220	0.000	0.235	0.021
16–17 "	0.220	0.013	0.221	0.014	0.221	0.007
17–18 "	0.206	0.015	0.206	0.016	0.213	0.008
20–21 "	0.211	0.010	0.210	0.011	0.212	0.012

Table 3

ZONE	$\overline{W}'_{band}$	σ_W	$\overline{R}_{band}$	σ_R
E	18.4	± 1.7	0.210	± 0.016
N	18.0	1.8	0.202	0.017
S	18.1	1.8	0.205	0.017
All zones	18.2	1.8	0.206	0.017

It is true that in the temperate zones the values of W_{band} are 0.3 – 0.4 Å lower than in the equatorial zone but these differences are substantially less than the measurement error.

The variations in $\overline{W}_{band}$ from day to day are rather substantial — the equivalent 6190 Å band width varies from 16.1 to 20.6 Å, i.e., by 4.5 Å. Since the number of spectrograms used to determine W_{band} in each zone is not the same and varies from one to ten, the reliability of the quantities W_{band} and R_{band} is different for each day. Nevertheless, we should note the following peculiarity. A clear correlation is observed between the values of the equivalent width for N and S (the correlation coefficient is r (N, S) = + 0.89), while for values of W_{band} for the equatorial zone the quantities mentioned above correlate very poorly: $r(N,E) = +0.43$, $r(S,E) = +0.64$.

The observations of 1959 could not be considered sufficient for clarifying the question concerning the short term variations in the intensity of methane absorption in Jupiter's atmosphere. Therefore, in 1960 spectrophotometric 165 observations of the equatorial region of the planet were again carried out. The methods were identical to those used in 1959. Each night not less than 10 – 12 spectrograms of the equatorial regions were taken and these were used to determine the equivalent width of the 6190 Å band. The results of the observations are presented in Table 4, where W_{band} is the equivalent width, R_{band} is the depth of the absorption band σ is the root – mean – square error of each determination, n is the number of spectrograms, L_1 is the longitude of the central meridian of Jupiter in system I.

We can see that the dispersion of the values W_{band} from day to day in this case is substantially less than in 1959 (Figure 2). It is interesting to note that the root – mean – square error of one measurement in our observations conducted in 1959 and 1960 is usually smaller than the probable error cited in the work of Hess (Reference 1) even when the number of measurements is small. Since the probable error and the root – mean – square error are associated with a relationship $r = 0.674\sigma$, it turns out that the internal convergence of the measurements of the equivalent absorption band width of methane for spectrograms with small dispersion is even slightly better than for spectrograms with dispersion substantially greater than for the AST-9 spectrograph.

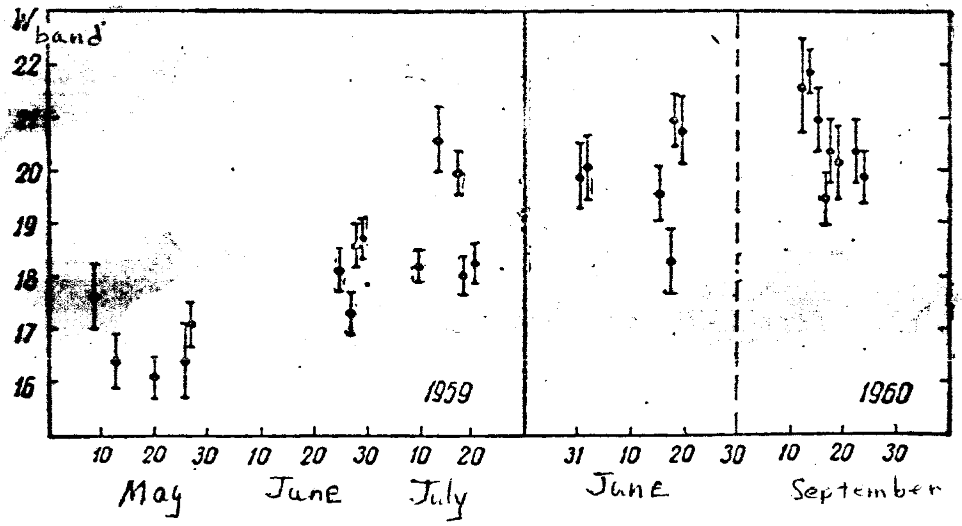

Figure 2. Variation in the equivalent widths of CH_4 6190 Å band in 1959 and 1960. The vertical segments correspond to the root-mean-square error in the average data.

Thus we can see that the oscillations of the absorption band intensity for methane from day to day is very small although in some cases they exceed the limits of possible measurement errors. Apparently the variation of a seasonal nature can be considered to be real and these lie in the limits 1 - 2 Å of the equivalent width. No preferred increase or decrease in the methane bands is observed in any particular regions of jovicentric longitudes.

During the period November - December 1961 observations of Jupiter were again carried out using the AST-9 spectrograph installed on the AVR-2 200 mm reflector. The spectra of Jupiter's equatorial zone were photographed. The results of the observations are shown in Table 5.

Unfortunately the results of 1961 are less reliable since the calibration of the negatives was carried out over individual pieces of the plates which 166 frequently results in inaccuracies. A clear correlation was observed between the obtained values of the equivalent absorption band width and the coefficient of the characteristic curve. It therefore became necessary to reduce somewhat the obtained values due to inaccurate calibration bearing in mind that the conditions of development were strictly maintained.

TABLE 4

1960	$W_{band} \pm \sigma_A$	σ	$R_{band} \pm \sigma_A$	σ	n	L_I
31 May –1 June	19,9±0,6	1,8	0,221±0,006	0,016	12	243°
1—2 June	20,1±0,6	1,8	0,210±0,005	0,015	12	36
15—16 „	19,6±0,5	1,5	0,211±0,004	0,013	12	71
17—18 „	18,3±0,6	1,7	0,200±0,004	0,011	12	3
18—19 „	21,0±0,5	1,4	0,228±0,004	0,013	11	164
19—20 „	20,8±0,6	1,8	0,220±0,004	0,013	12	307
12—13 september	21,6±0,9	1,8	0,231±0,008	0,016	5	339
13—14 „	21,9±0,4	1,1	0,230±0,005	0,015	10	133
15—16 „	21,0±0,6	1,8	0,230±0,005	0,016	11	65
16—17 „	19,5±0,5	1,6	0,220±0,006	0,018	11	216
17—18 „	20,4±0,6	1,7	0,236±0,004	0,011	10	13
18—19 „	20,2±0,7	2,1°	0,230±0,005	0,015	12	162
22—23 „	20,4±0,6	1,3	0,223±0,005	0,010	7	64
23—24 „	19,9±0,5	1,6	0,224±0,004	0,014	12	225
Average	20,4±0,3	0,9	0,222±0,003	0,010	149	

TABLE 5

1961 г.	$W_{band} \pm \sigma_A$	σ	$R_{band} \pm \sigma_A$	σ	n
22—23 November	19,6±0,5	1,5	0,224±0,003	0,009	10
23—24 November	19,5±0,7	1,9	0,211±0,009	0,026	9
„ „	19,1±0,7	2,1	0,203±0,005	0,017	10
28—29 November	19,3±0,5	1,6	0,218±0,005	0,015	11
8—9 December	17,1±0,6	2,1	0,206±0,005	0,015	12
10—11 „	18,7±0,5	1,6	0,213±0,005	0,016	12
11—12 „	18,8±0,7	1,6	0,202±0,003	0,007	5
12—13 „	18,4±0,4	1,1	0,202±0,004	0,013	10
14—15 „	17,7±0,6	2,1	0,204±0,004	0,014	11
18—19 „	16,2±0,9	3,1	0,199±0,005	0,017	12
19—20 „	18,0±0,7	2,3	0,212±0,005	0,017	11
28—29 „	17,0±0,9	2,3	0,199±0,005	0,013	7
2—3 Jan 1962	18,5±0,6	1,6	0,217±0,005	0,014	8
Average	18,3±0,3	1,0	0,208±0,002	0,008	128

Note : Commas in tables represent decimal points.

As we can see, in 1961 the limits for the variation of the equivalent width of the methane band are approximately the same as in 1959. The relationship between W_{band} and R_{band} turns out to be linear for all of the years, i.e., $W_{band} \sim R_{band}$.

Such are the results of the observations. Below we shall consider several possible reasons for the variation in the intensity of methane absorption bands on Jupiter and shall attempt to evaluate their role in such variations.

CERTAIN DATA ON THE STRUCTURE OF JUPITER'S ATMOSPHERE 167

It is known that under laboratory conditions methane produces absorption bands only in the infrared region of the spectrum. The detection of overtone and combination methane vibration bands in the visible region of the spectrum becomes possible only when the linear thickness of the methane layer is very great and when the pressure is very high. Consequently the absorption (α_{band}) coefficient of methane in the 6190 Å ($16\nu_3$) band must be very small. It is possible to determine the optical thickness of the effective absorbing layer of methane along the depth at the center of the absorption band in the same manner as for an absorption line

$$2\tau_{band} = \ln \frac{I_{band}}{I_0} = \ln (1 - R_{band}) \qquad (1)$$

where I_0 is the intensity of the reflected radiation outside the absorption band,

I_{band} is the same at the center of the absorption band,

R_{band} is the depth of the band.

In most of the works concerned with the study of absorption bands in the spectrum of Jupiter (reference 1, 5) it was assumed that absorption by methane and ammonia occurs only in that layer of the atmosphere which is above the visible surface of the planet, i.e., over the surface of the dense cloud layer. This upper layer of the atmosphere which is free of clouds may be assumed to consist only of a pure gas without noticeable additions of aerosol component. The entire quantity of methane and ammonia determined from spectral observations on the intensity of absorption bands is usually attributed to this pure gaseous layer.

Actually the optical thickness τ_{band} obtained by observing the intensity of absorption bands does not correspond to absorption merely in the pure gaseous layer. The observed absorption of methane in Jupiter's atmosphere is produced by two effects: 1) absorption in the pure gaseous layer with a linear reduced thickness l_g, in which case

$$\tau_{bg} = \int_0^{l_g} a_{band} \, dl, \tag{2}$$

and 2) the absorption by methane present in the cloud layer. The latter effect is manifested by the fact that the albedo of the cloud layer which has a large optical thickness ($\tau_s \to \infty$) in the continuous spectrum for wave lengths corresponding to the methane band will be lowered. Indeed, the parameter

$$\lambda_s = \frac{\sigma}{\sigma + a}, \tag{3}$$

which characterizes the relationship between the scattering coefficient σ and the continuous true absorption α in the atmosphere and which determines the albedo of the medium with an infinite optical thickness is given by the following expression in the absorption band

$$\lambda_{band} = \frac{\sigma}{\sigma + \alpha + \alpha_{band}}. \qquad (4)$$

The magnitude of methane absorption in the cloud layer can be expressed by the optical thickness τ_{bo} only conditionally without giving it the meaning of expression (2) and assuming that the intensity of the methane band obtained from observations corresponds to the sum

$$2\tau_{band} = 2\tau_{bg} + \tau_{bo}. \qquad (5)$$

A two layer model of the absorbing Jupiter atmosphere of this type was considered in Reference 4 as a possible explanation for the absenee in the variation of methane band intensity as a function of position on the planet's disk. It turned out that in order to approximately maintain a constant band intensity in all parts of Jupiter's disk, the layer of pure gas must have an optical thickness at the center of the 6190 A absorption band which is equal to $\tau_{bg} \cong 0.05$, whereas the observed "effective" optical thickness is equal to $2\tau_{band} = 0.25$.

Proceeding from the quantity of methane obtained by Kuiper from the total intensity of absorption bands (15000 cm under normal conditions or with a partial pressure $P_{band} = 10.7$ gm/cm^2), we can use these data to determine the quantity of methane in the purely gaseous layer

$$\frac{P_g}{P_{band}} = \frac{N_g}{N_{band}} = \frac{W_g}{W_{band}} = \frac{R_g}{R_{band}} = \qquad (6)$$

$$= \frac{1-e^{-2\tau_{bg}}}{1-e^{-2\tau_{band}}} = \frac{1-0.905}{1-0.779} = \frac{0.095}{0.221} = 0.430.$$

$$P_g = 0.430\, P_{band} = 0.430 \cdot 10.7\, gm/cm^2 = 4.6\, gm/cm^2. \qquad (7)$$

Here P_g is the partial pressure of methane at the base of the purely gaseous layer under normal conditions, N is the number of absorbing molecules.

At the present time the most acceptable model of Jupiter's atmosphere is one of the two models proposed by Kuiper —his model "b" (Reference 5). According to this model the purely gaseous layer situated above the cloud layer is divided into two zones — an isothermal stratosphere and an adiabatic zone which contains the upper part of the cloud layer. Proceeding from the proposed ratio of hydrogen, helium and methane (in model "b" H_2: H_e: CH_4 = 195:308:1.4), Kuiper obtains a ratio of specific heats C_p and C_v equal to $\gamma = \frac{C_p}{C_v} = 1.56$ and an average molecular atmospheric weight of $\mu = 3.26$. The latter quantity is confirmed by the observations of Baum and Code (Reference 6) on the blanketing by Jupiter of the star σ.

The dry adiabatic temperature gradient in Jupiter's atmosphere above the cloud layer turns out to be equal to

$$G = \frac{dT}{dh} = 4 \cdot 10^{-5}\ deg/cm.$$

The upper boundary of the cloud layer according to Kuiper (Reference 5) lies at 21 km below the tropopause and has a temperature of 168°K (Figure 3). The temperature of the stratosphere is 86°K. The pressure at the upper boundary of the cloud layer is 2 atmospheres. Apparently the latter quantity should be reduced in accordance with (7). Taking the above relationship between the number of hydrogen molecules, helium molecules and methane molecules which gives us the mass ratio

$$\frac{H_2+He}{CH_4}=\frac{195\times2+308\times4}{1.4\times16}=72.5, \tag{8}$$

we obtain the following values for the total pressure 169

$$P_c=72.5\cdot P_\gamma\cdot\frac{g_{10}}{g_3}=72.5\cdot4.6\cdot2.64=880 gm/cm^2. \tag{9}$$

NOTE: 10 = Jupiter.

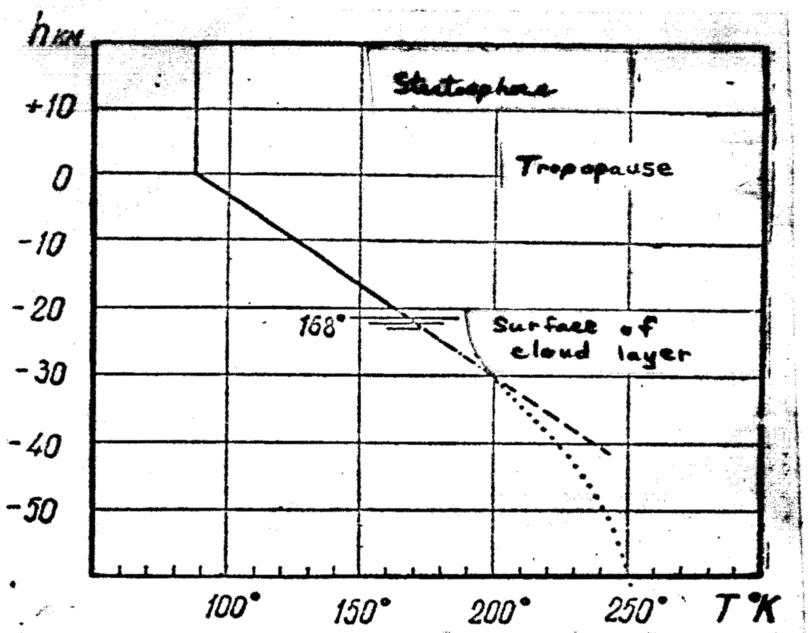

Figure 3. Temperature distribution in Jupiter's atmosphere according to Kuiper. The dots represent the most probable curve for the temperature variation below the cloud layer boundary according to Pik.

Here $g_{\text{Ю}}$ and $g_{\text{Е}}$ are, respectively, the accelerations due to gravity on Jupiter and on the earth. Thus the total atmospheric pressure at the upper boundary of Jupiter's cloud cover is equal to 0.85 atmospheres. This quantity apparently is the lower pressure level at the boundary of the cloud cover because initial values are arbitrary to some degree and the calculations are quite approximate.

From this we can establish the optical thickness and the linear extent of the purely gaseous layer along the altitude.

The optical thickness of this layer in the continuous spectrum (τ_H) is determined by the Kuiper method (Reference 5). The Rayleigh scattering of hydrogen is 0.23 while the helium scattering is 0.017 of its scattering in the earth's pure air. Therefore the ratio of air masses for the pure gaseous layer of Jupiter and of the earth's atmosphere is equal to

$$\frac{M_{\text{Ю}}}{M_{e}} = 0.23\, P_c \frac{g_{з}}{g_{\text{Ю}}}\, D_{H_2} + 0.017\, P_c \frac{g_{e}}{g_{\text{Ю}}} D_{He} = 0.0183, \tag{10}$$

where D_{H_2} and D_{He} represent the proportion of hydrogen and helium in the mass of Jupiter's atmosphere. $P_c = 0.85$ atmospheres. The optical thickness of the purely gaseous layer in the continuous spectrum is $\tau_H = 0.018\tau_e$. According to data presented in the article by Ven de Holst (Reference 7), the optical thickness τ_e of the earth's atmosphere for pure air and a wave length of 3530 Å is equal to 0.474. Then $\tau_{H3530} = 0.008$. Kuiper obtained $\tau_{3500} \cong 0.03$ for the model "b". Since $\tau_H \sim \lambda^{-4}$ we can compute the values τ_H for the visible region of the spectrum (Table 6).

In the entire visible region of the spectrum, the optical thickness of a purely gaseous layer outside the absorption band is equal to $\tau_H < 0.01$.

The linear extent along the altitude of Jupiter's atmosphere above the cloud layer may be obtained if we assume some boundary density since the isothermal atmosphere has no true boundary. 170

TABLE 6

λ	4000 Å	4500 Å	5000 Å	5500 Å	6000 Å	6500 Å
τ_H	0,0050	0,0032	0,0021	0,0015	0,0010	0,0008

As an arbitrary boundary for Jupiter's atmosphere we assume a zone where the pressure is equal to 10^{-6} mm Hg. On the earth this corresponds approximately to an altitude of 150 - 170 km. Higher altitude layers may be assumed to have small optical effectiveness. Proceeding from the value of the pressure at the upper boundary of the cloud layer $P_0 = 0.85$ atmospheres = 645 mm of mercury and a temperature of $T_0 = 168°K$ we find the pressure at the boundary of the adiabatic zone (tropopause)

$$P = P_0 \left(1 - \frac{G \cdot h_1}{T_0}\right)^{\frac{\mu g}{RG}}. \tag{11}$$

where $G = \frac{dT}{dh} = 4 \cdot 10^{-5}$ deg/cm and $h_1 = 21 \cdot 10^5$ cm.

$$P_1 = 645 \left(1 - \frac{4 \cdot 10^{-5} 21 \cdot 10^5}{168}\right)^{2,63} = 104 \text{ мм pm. cm.} \tag{12}$$

For an altitude of $h > 21$ km we use the barometric equation

$$P = P_1 e^{-\frac{g\mu}{RT}(h - h_1)},$$

(13)

from which

$$h - h_1 = -\frac{RT}{g\mu} \cdot \ln \frac{P}{P_1} = 148 \text{ км}. \quad (14)$$

Consequently the total altitude is established as 169 km. Almost total coincidence with the analogous altitude for the earth's atmosphere is quite natural since the pressure gradient for the atmospheres of Jupiter and the earth are almost the same.

POSSIBLE REASONS FOR THE VARIATION IN THE INTENSITY OF METHANE ABSORPTION BANDS

By using the above arrangement of Jupiter's atmosphere we can point out two possible reasons for the variations in the observed magnitude of methane absorption in the planet's spectrum.

1. Variation in the linear thickness of the purely gaseous layer due to the variation in the altitude of the effective upper boundary of the cloud layer for which we can assume a definite density of the dispersion phase. The vertical displacements of the upper boundary of the cloud layer may be associated with a different intensity in the circulation of gaseous masses in Jupiter's atmosphere and with the processes of sublimation and volatilization of particles (ammonia crystals) which comprise the cloud layer, and which depend on the temperature at the boundary of the cloud layer.

2. The variation in methane content in the upper layers of Jupiter's atmosphere due to photochemical processes produced by the action of solar

radiation. In this case the linear thickness of the purely gaseous layer /7/ remains almost constant and only the number of methane molecules in the gaseous and cloud layers changes under the action of short wave photon and corpuscular solar radiation.

The work of V. I. Cherednichenko (Reference 8) considered the processes of dissociation and ionization of comet molecules by the ultraviolet and corpuscular solar radiation. By using data presented in this work we can compute the life t of a methane molecule in Jupiter's atmosphere using the equations for corpuscular radiation

$$t_{\text{к}} = \frac{1}{\sigma_{\text{к}} n_{\text{н}+} V_{\text{н}+}} \tag{15}$$

NOTE: K = Corpuscular.

and for photon radiation

$$t_{\Phi} = \frac{1}{\sigma_{\Phi} Q w}, \tag{16}$$

NOTE: Φ = photon.

where σ_K and σ_Φ are the effective cross sections of the processes in the solar radiation field, n_H and V_H are the concentration and velocity of protons in corpuscular fluxes, Q is the flux of effective photon radiation at the surface of the sun, w is the dilution factor.

For Jupiter (r = 5.2 a.u.) the dilution factor is $w_{\text{ю}} = 2 \cdot 10^{-7}$, while the life of methane molecules compared with the value computed by V. I. Cherednichenko for r = 1 a.u. will be equal to

$$t_{\text{кю}} = \frac{1}{\sigma_{\text{к}} n'_{\text{н}+} V'_{\text{н}+}} = \frac{t_{\text{к}} n_{\text{н}+} V_{\text{н}+}}{n'_{\text{н}+} V'_{\text{н}+}}, \tag{17}$$

$$t_{\phi w} = \frac{1}{\sigma_{\phi} Q w'} = \frac{t_{\phi} w}{w'} . \qquad (18)$$

Depending on the initial conditions we establish the life of methane molecules for different dissociation processes and present the results in Table 7. In the table, t corresponds to the initial levels assumed by V. I. Cherednichenko: r = 1 a.u., $n_{H^+} = 600$ cm^{-3}, $V_{H^+} = 500$km/sec, w = 5.4 x 10^{-6}. The values t_{K1} correspond to the following conditions: r = 5.2 a.u., $n_{H^+} = 600$ cm^{-3} at the distance of Jupiter $n'_{H^+} = 22$ cm^{-3} and $V'_{H^+} = 500$ km/sec. For t_{K2} the following conditions are assumed: r = 5.2 a.u., $n'_{H^+} = 22$ cm^{-3}, $V'_{H^+} = 1000$ km/sec, Q' = 100 Q. The value Q' corresponds to the ultraviolet radiation from bright flares and chromospheric bursts. For average values of solar radiation flux characteristics the life t_{K1} of the CH_4 molecule in Jupiter's atmosphere is measured by tens of days. Corpuscular radiation rather than photon radiation is most effective as pointed out in Reference 8. The solid angle for the flux of corpuscular radiation proceeding from the active region of the sun is equal to 8°- 9° (Reference 9, 10) which at the distance of Jupiter represents a width of the order of 10^{8} km. The maximum effect of corpuscular fluxes occur at the polar and temperate regions of Jupiter if it has a noticeable magnetic field. In connection with this, it is interesting to remember the correlation obtained in 1959 between the equivalent width of the methane band for the northern and southern temperate zones. Apparently it is for the polar regions that efforts should be made to establish a relationship between the possible oscillations in the intensity of methane absorption bands and solar activity; however, from the presented data it follows that the rapid short term variations in methane content in Jupiter's atmosphere due to solar activity are doubtful. Indeed a comparison of the diurnal oscillations of the equivalent width of the methane band with solar activity does not yield noticeable correlation.. 172

Apparently the effect of solar activity will manifest itself only in long term variations in the intensity of absorption bands associated with the variation in the total level of solar radiation during the eleven year cycle. Data are available on the variation in the form, intensity and color of the cloud bands on Jupiter during the period of the eleven year solar cycle (References 11, 12). However, we should bear in mind that the variation of the heliocentric distance of Jupiter takes place with almost the same period from 5.45 to 4.97 *a. u.*, which also produces a variation in the magnitude of the radiation flux obtained by the planet from the sun by approximately 20 percent.

TABLE 7

Reaction	t	t_{101}	t_{102}
$CH_4 + H^+ \rightarrow CH_4^+ + H \rightarrow$	$0^d.151$	$4^d.07$	$2^d.04$
$1/ \rightarrow CH_4^+ + H^+ \rightarrow CH_3^+ +$			
$+ H + H^+$	3.01	81.2	0.81
$2/ \rightarrow CH_4^+ + h\nu \rightarrow CH_3^+ + H$	8.05	217.5	2.18
$CH_4 + H^+ \rightarrow CH + 3H + H^+$	0.733	19.8	9.9
$CH_4 + H^+ \rightarrow CH_2 + H + H^+ + H$	1.08	29.2	14.6
$CH_4 + H^+ \rightarrow CH_3 + H^+ + H$	0.417	11.3	5.7
$CH_4 + H^+ \rightarrow CH_2 + 2H + H^+$	0.606	16.4	8.2
$CH_4 + H^+ \rightarrow CH + 2H + H^+ + H$	0.415	11.2	5.6

If we assume that the variations in the intensity of methane absorption bands occur only due to the variation in the thickness of the purely gaseous layer, we can use the results of the observations to find the possible limits for the oscillation in the altitude of the upper cloud layer boundary.

Instead of the pressure we can substitute the number of methane molecules into Equation (11) since methane does not condense under Jupiter's atmospheric conditions and follows the same law for the decrease in density with altitude as hydrogen and helium. Then

$$\frac{N}{N_0} = \left(1 - \frac{G \cdot \Delta h}{T_0}\right)^{\frac{\mu g}{RG}}. \tag{19}$$

On the other hand if we assume that $\tau_{bq} \sim N$,

$$\frac{N}{N_0} = \frac{\tau_{bq1}}{\tau_{bq2}}. \tag{20}$$

If we assume that $\tau_{bq} = 0.050$ is the average optical depth of the purely gaseous layer, the observed variations in W_{band} and R_{band} will correspond to a variation in τ_{bq} equal to 0.014, i.e., the limiting values of τ_{bq} will be 0.043 and 0.057. Then

$$\frac{N}{N_0} = \frac{0.043}{0.057} = 0.755. \tag{21}$$

and

$$\Delta h = \frac{1 - \sqrt[2.65]{0.755}}{4} \cdot 168 = 4.2 \text{ км}. \tag{22}$$

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Thus the possible variations in the altitude of the upper boundary for the cloud layer are approximately 4 km. The quantity Δh which is obtained depends very little on the temperature T_0 which is assumed for the surface of the cloud layer.

The authors are very grateful to N. D. Kalinenkov for a series of important remarks and suggestions concerning the preparation of this article for publication.

REFERENCES

1. Hess, S. L. Astroph. J., 1953, 118, No. 1, 151-160.

2. Kiess, C. C., Corliss, C. H. and Kiess, H. K. Astroph. J., 1960, 132, No. 1, 221 - 231.

3. Teyfel', V. G. Astronom. tsirkulyar AN SSSR, No. 201, 1959.

4. Teyfel ', V. G. Izv. Komissii po fizike planet, 1960, 1, 93 - 104.

5. Kuiper, G. P. The Atmosphere of the Earth and Planets. 2 ed., 1952.

6. Baum, W. and Code, A. Astron. J. 1953, 58, 108 - 112.

7. Van de-Holst, G. Atmospheres of the Earth and of the Planets (Atmosfery Zemli i planet). M., I.L. 1949.

8. Cherednichenko, V. I. Astronom. zhurnal, 1959, 36, No. 2, 254 - 263.

9. Engenson M., Gnevyshev, M., Ol', A. and Rubashev, V. Solar Activity and its Terrestrial Manifestations (Solnechnaya aktivnost' i yeye zemnyye proyavleniya). M., GTTI, 1948.

10. Physics of Solar Corpuscular Fluxes (Fizika solnechnykh korpuskulyarnykh potokov). Collected Works. Izd-vo AN SSSR, 1957.

11. Barabashov, N. P. Results of the Photometric Investigations of the Moon and of the Planets at the KhGU Astronomical Observatory (Rezul'taty fotometricheskikh issledovaniy Luny i planet na Astronomicheskoy observatorii KhGU). Khar'kov, 1957.

12. Shapiro, R. J. Meteorol. Vol. 10, No. 5, 350-355, 1953.